IONOSPHERIC ABSORPTION IN THE VLF BAND

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ABSTRACT. Experiments on the propagation of VLF waves at great distances reveal that there is an absorption band for frequencies in the range of 3 kc/s. In the present paper an attempt has been made to account for this absorption theoretically. From the expression of the reflection coefficient of the ionosphere at VLF, the absorption in *dB* has been computed. The plots of absorption as a function of frequency for different values of the angle of incidence at the Ionosphere show that when the incident angle is 80°, there is a dip in the absorption curve in the 3 kc/s range. This explains the absorption band that is observed in this frequency range.

INTRODUCTION

Radio wave propagation at very low frequencies (from 3 to 30 k/s) is characterized by the fact that the ground attenuation is very low and the sky waves are almost totally reflected from the ionosphere which has a height of the order of 60 to 80 km. In fact, the VLF waves which have travelled considerable distances act as if they were propagated through a wave-guide formed by the earth and the lower edge of the ionosphere. The attenuation under such conditions is that caused by spreading and absorption of the energy by the ground and the ionosphere. Taylor (1960) studied the attenuation rates for VLF waves and found that for 6 kc/s the attenuation was about 7 to 9 db/1000 km and decreased to about 1 to 3 db/1000 km at frequencies above 10 kc/s. Wait and Spies (1960) could account for these observed results theoretically from the point of view of modal propagation.

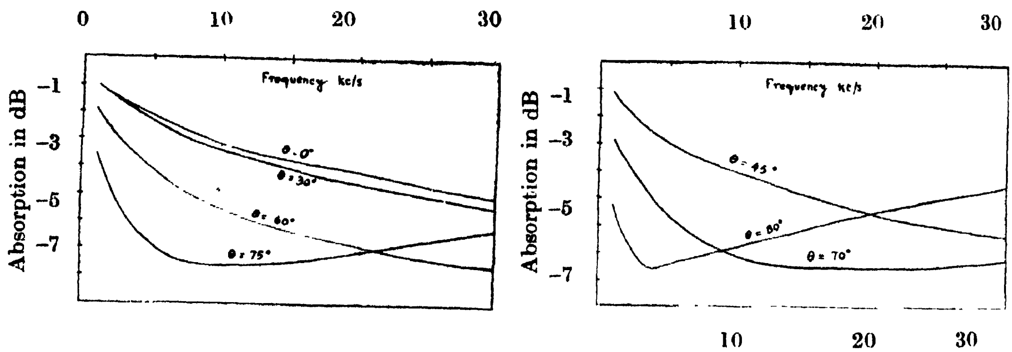
Despite the fact that the VLF waves propagate to great distances with small attenuation their use has been neglected for many years. Recently, however, with the pressing need for long-range navigational systems, world-wide communication systems and tracking of atmospheric storms and hurricanes, the desirable transmission properties of VLF are again being utilized. In view of the gaining importance of VLF in long-range communication, systematic experiments are being carried out at Boulder (USA), Slough (UK) and Toyokawa (Japan) with a network of receiving stations distributed through respective countries to study in detail the propagational characteristics of these waves. The results of these experiments show the presence of an absorption band for frequencies of the order of 3 kc/s for long-range propagation. In the present paper an attempt is made to explain this absorption band in a very simple way.

RESULTS AND DISCUSSION

For the reflection coefficient of the ionosphere at VLF we write (Bhattacharya *et al*, 1964)

$$|R(\omega, \theta)| \approx \frac{[1+(\omega_r/\omega)^2 \cos^4 \theta]^{\frac{1}{2}}}{1+(\omega_r/\omega) \cos^2 \theta+(2\omega_r/\omega)^{\frac{1}{2}} \cos \theta} \tag{1}$$

where θ is the angle of incidence at the ionosphere and $\omega_r = 4\pi Ne^2/m\nu$, N being the electron number density, e the electronic charge in esu, m the electronic mass in grams, ν the electron collisional frequency and ω the angular frequency of the exploring wave in the VLF band. Our laboratory experiments show the average ionospheric reflection height at 86 km. Substituting the value of N ($\sim 10^3$), ν ($\sim 3{\cdot}16 \times 10^6$), (Ratcliffe, 1960) at this height and also e ($= 4{\cdot}8 \times 10^{-10}$ esu) and e/m ($= 5{\cdot}2 \times 10^{17}$) we get $\omega_r \simeq 10^6$. From (1) we have $20 \log_{10} |R(\omega, \theta)|$ for the ionospheric absorption in decibels for VLF waves. The plots of this expression as a function of $\omega/2\pi$ for different angles of incidence are given in figs. 1(a) and 1(b), We observe that for $\theta = 80°$, that is, for long-range propagation their is a dip in the absorption curve in the range of 3 kc/s, corresponding to maximum absorption. This is in complete accord with the experimental observation.



Figs. 1.(a) and (b) Comes showing absorption *vs*, frequency for different angles of incidence.

In developing (1) we have applied the Fresnel's reflection coefficient to the ionosphere, thereby limiting the ionosphere to a sharply bounded continuum. In fact the reflection coefficient is in the form of a series (Wait, 1962) of which the first term is a Fresnel type and the succeeding terms account for the finite thickness of the ionospheric layer. But, in view of the fact that there is a very sharp gradient in electron density in the region at a height 60–80 km and also that the wavelengths of the VLF waves are much larger than the scale of horizontal irregularities, our present consideration of ionosphere as a sharply bounded continuum is not unjustified. Further, the effect of the earth's magnetic field can also be neglected in view of the obliqueness of the incident rays at the ionosphere.

It may be pointed out that from (1) we have no knowledge how reflection coefficient varies as a function of frequency at grazing incidence. Moreover, it fails to account for the effect of the earth's curvature which is prominent at grazing and near-grazing incidence.

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